NG-NRMM(I) for Intelligent Mobility AVT-248 Thrust 4

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Outline

Definitions: **NG-NRMM** - manned **NG-NRMM(I)** – intelligent mobility

- ***NATO AVT-248 Thrust 4 Approach***
- ***Prototype development***
- ***Challenges***

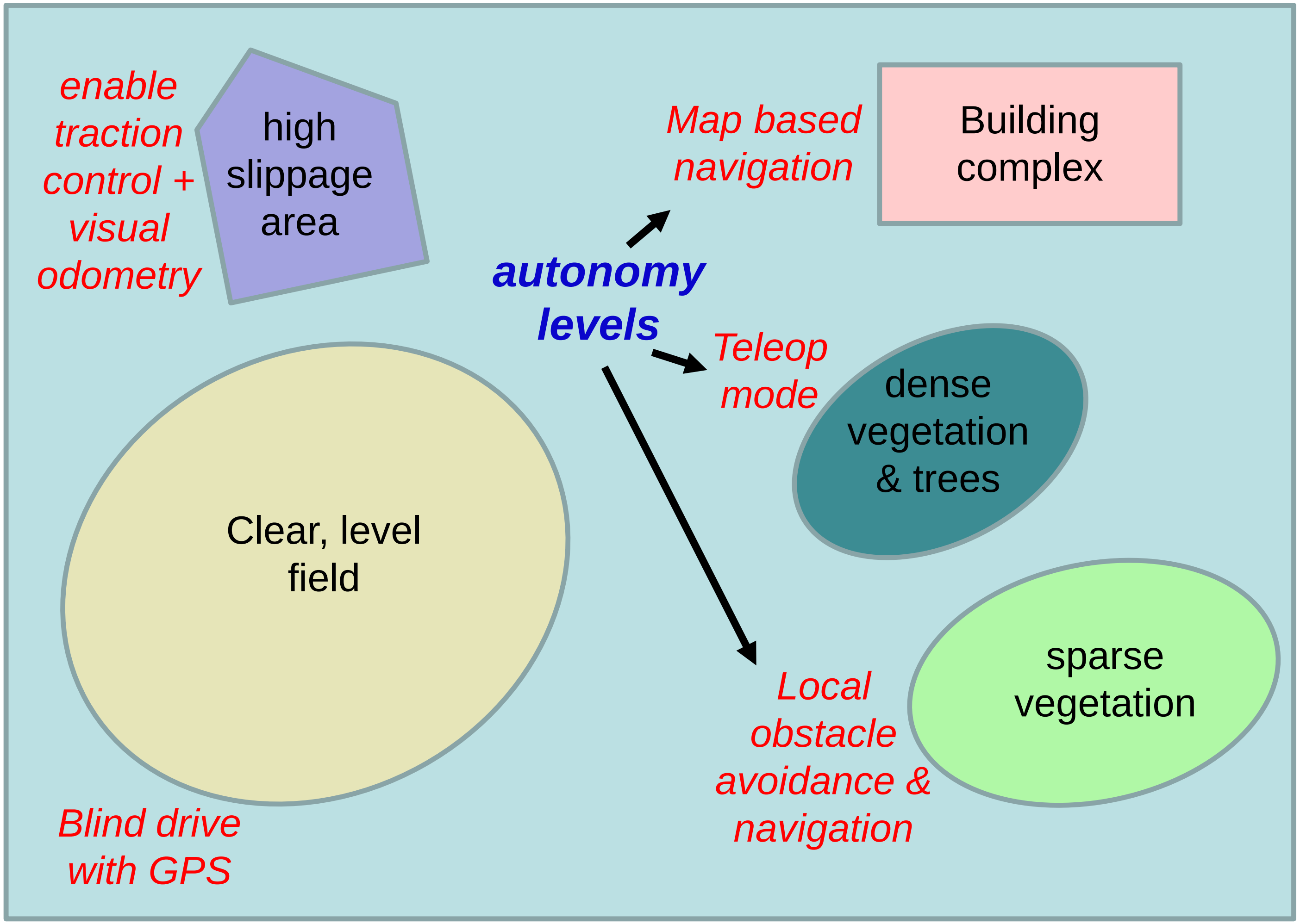
Assumptions

- *The goal of NG-NRMM(I) is **not** to develop better autonomy, but instead is to define methods and approaches for developing predictive mobility performance models for **provided** intelligent vehicles for operations and acquisition use.*
- *Will use NG-NRMM vehicle dynamics **M&S approach** - extended to include autonomy sensors, environment and software in the loop*

Mobility Plan for Supervised Autonomy

- Mission execution requires meeting multiple (and possibly conflicting) objectives (eg. safety, speed)
- Supervised autonomy requires a **mobility plan** for each region that judiciously manages the multiple **autonomy level options** (eg. SLAM, traction control), where each autonomy level represents a unique combination of intelligence "knob" settings (eg. sensors choice, terrain classification algorithm, map building)
  - Each knob setting's benefit comes at a cost (CPU, memory, algorithm cost, latency, sensors, bandwidth, operator guidance etc.)
- **Performance models** needed for NG-NRMM(I) intelligent vehicle directly depend on such mobility plans

Example Autonomy Scenario



Different intelligent mobility autonomy levels are required for different terrain and scenario conditions.

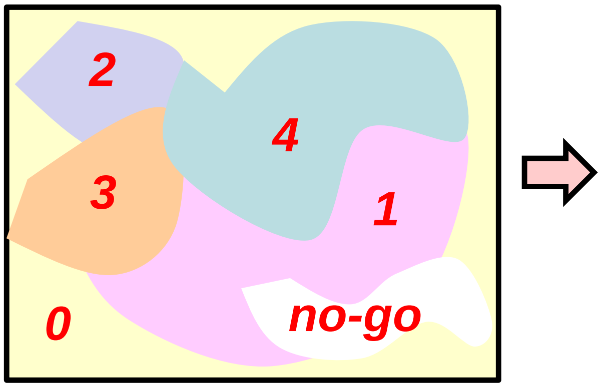
Autonomy Map Concept

- **Intelligent systems**
  - Broadly speaking, an intelligent system consists of a **collection of behaviors** that can be called upon individually & in combination to meet goals and handle contingencies for a range of scenarios.
  - Intelligence is like a toolbox with a set of tools. They are not all used simultaneously, but rather **selectively & sequentially** to meet scenario needs.
  - The degree of intelligence is defined by the extent to which the behaviors are chosen autonomously, or by the human supervisor.
- **Intelligent system performance depends on**
  - **Strategic:** the collection & quality of behaviors available in the toolbox
  - **Tactical:** the plan for using the behaviors to execute current scenario
- Operationally, the **autonomy map** is a data product for designing best tactical plans for executing the scenario at hand. Given a tactical plan, sims can be used to predict performance.

Autonomy Map

- An **autonomy map** is a data product that specifies guidance on best autonomy level to use across a region

Optimal autonomy level across the region



Autonomy Map

- An autonomy map's content is a function of the vehicle(s) characteristics, the terrain region, the desired performance metrics and scenario constraints.
- It is a generalization of go/no-go and speed made good maps for manned NRMM

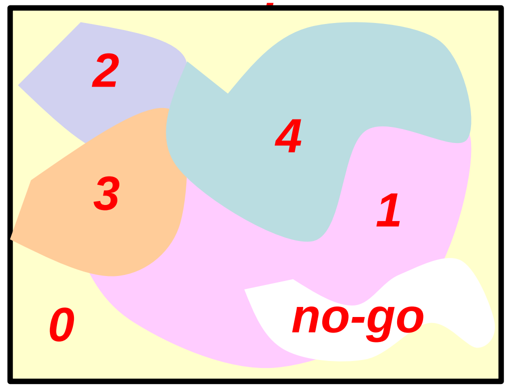
Autonomy Map Usage

Environment

Scenario with metrics

NG-NRMM(I)
Specific vehicle model & intelligence modes

Optimal autonomy levels across the



Autonomy Map

Component performance metric maps

Speed
Fuel consumption
Stability
Ride roughness
Slippage
Comm usage
…

The autonomy level recommendations from the **autonomy map** provide guidance for the proper operation of an intelligent vehicle across a region – and the generation of this map is the **primary responsibility** of NG-NRMM(I)

The speed-made-good map is the analogous "mobility plan" for the manned case.

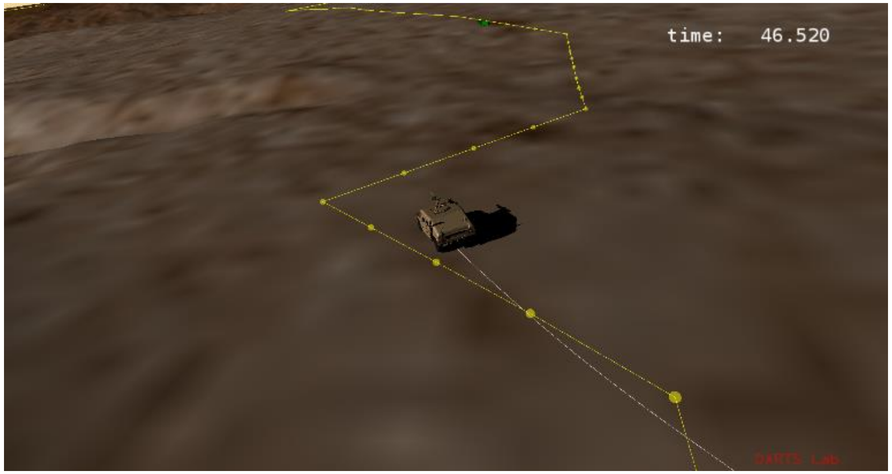
NG-NRMM(I) Prototype Objectives

- Used an intelligent mobility reference problem to flesh out the process for generating NG-NRMM(I) autonomy & performance maps
- Emphasis on breadth - increase detail and depth later

Monterey GIS terrain data sets, 2km square region, global path planning and waypoint following, improved mobility algorithms, feasible path detection; additional knobs for path planning and waypoint following

Developed Monte Carlo simulations for assessing mobility performance on HPC platform

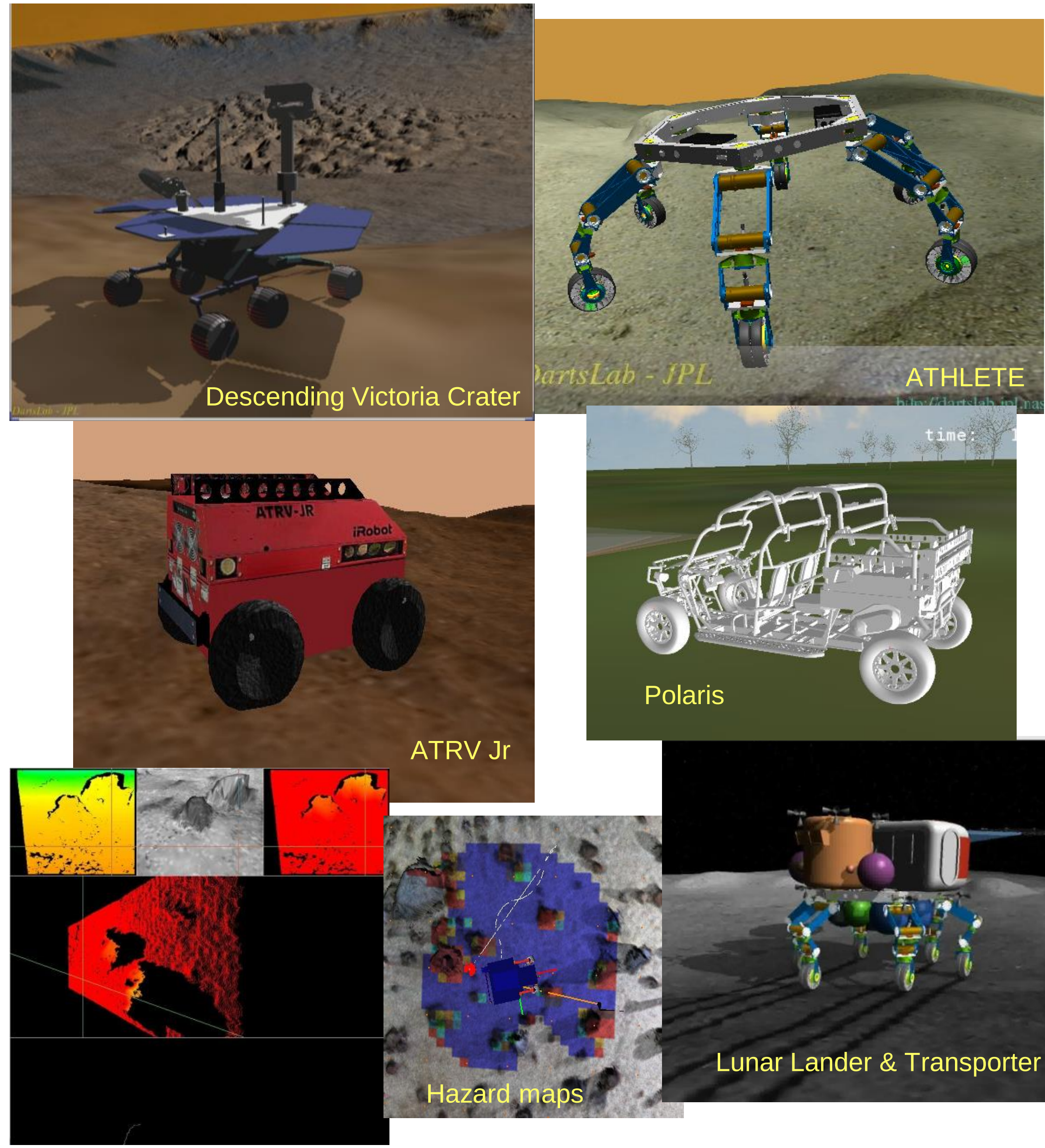
~2500 runs/autonomy level, ~15-20 autonomy levels per study batch



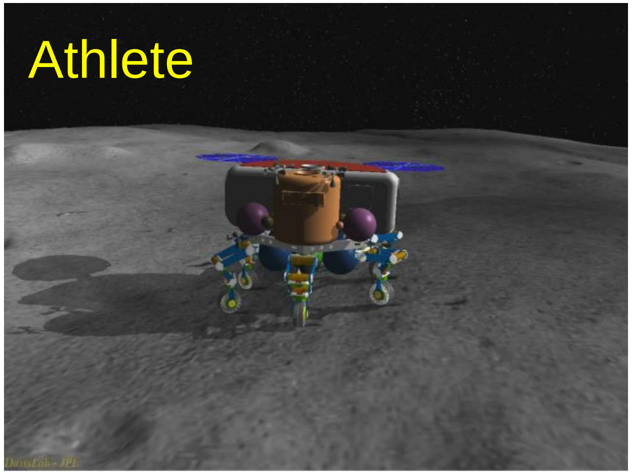
JPL ROAMS Ground Vehicle Simulator

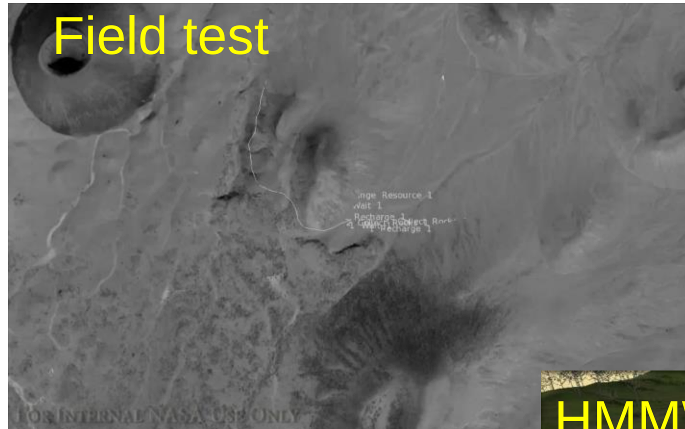
Darts Lab

- **Vehicle Platforms:** Single and multi-vehicle simulations; parameterized model classes
- **Motion:** Vehicle mobility, arm models, wheel/soil dynamics, Bekker soft soil, Fiala/Pacejka 2002 tire models
- **Hardware models:** Kinematics, dynamics, motors, encoders, IMU, inertial sensors, lidars, GPS
- **Camera sensors:** Image synthesis for cameras with non-idealities, rover and terrain shadows
- **Environment:** SimScape synthetic, empirical & analytic terrains, ephemerides interface for sun position
- **Closed-loop visualization:** Dspace 3D graphics (CAD/auto-generated vehicle models), data monitoring
- **Workstation/embedded use:** C++ & Python interface for configuring and closing the loop with software; Stand-alone Monte-Carlo capability.
- **Real-time:** dynamics, sub-second camera image synthesis
- **White and black box** simulation modes



ROAMS Mobility Simulations

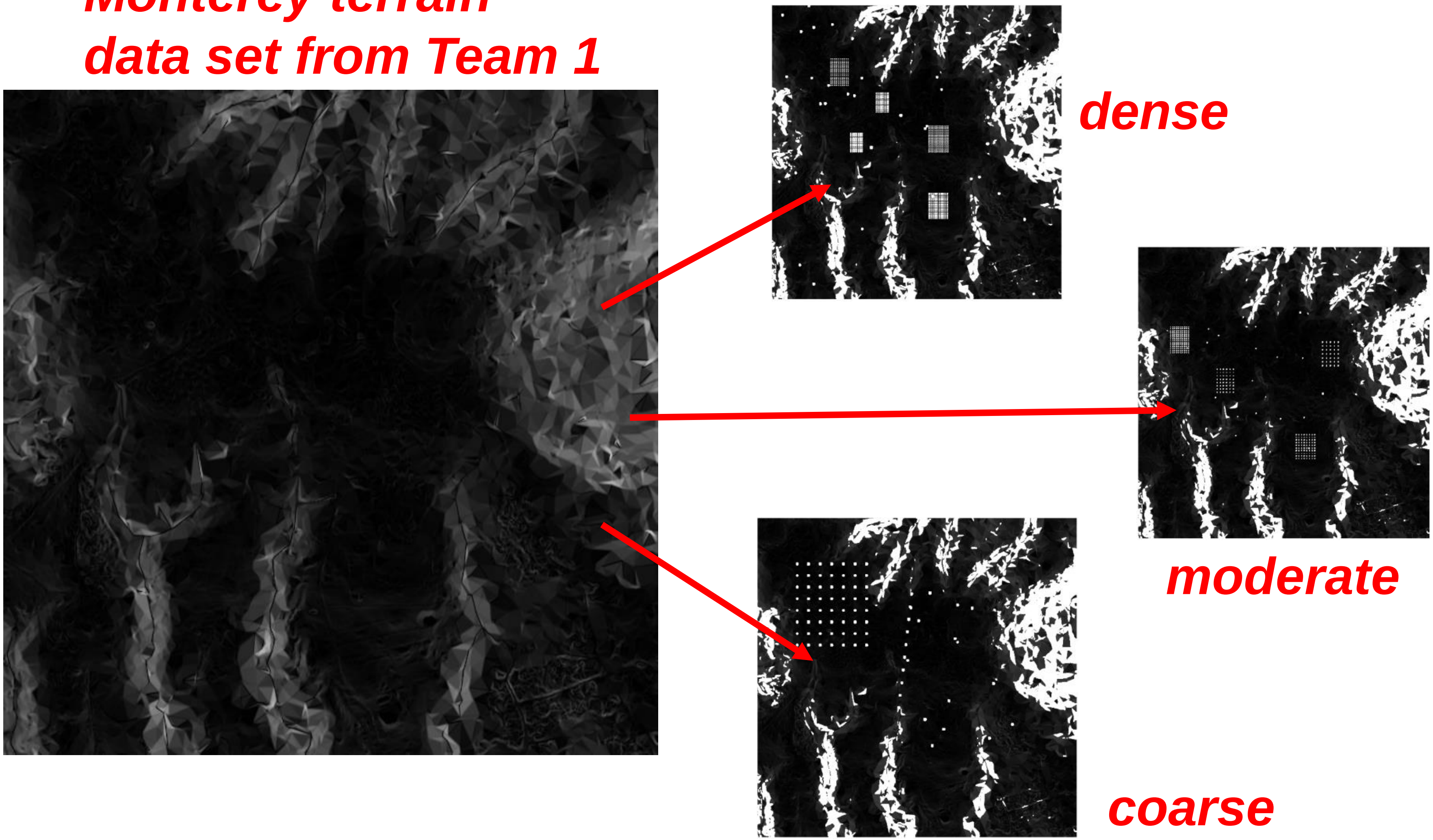




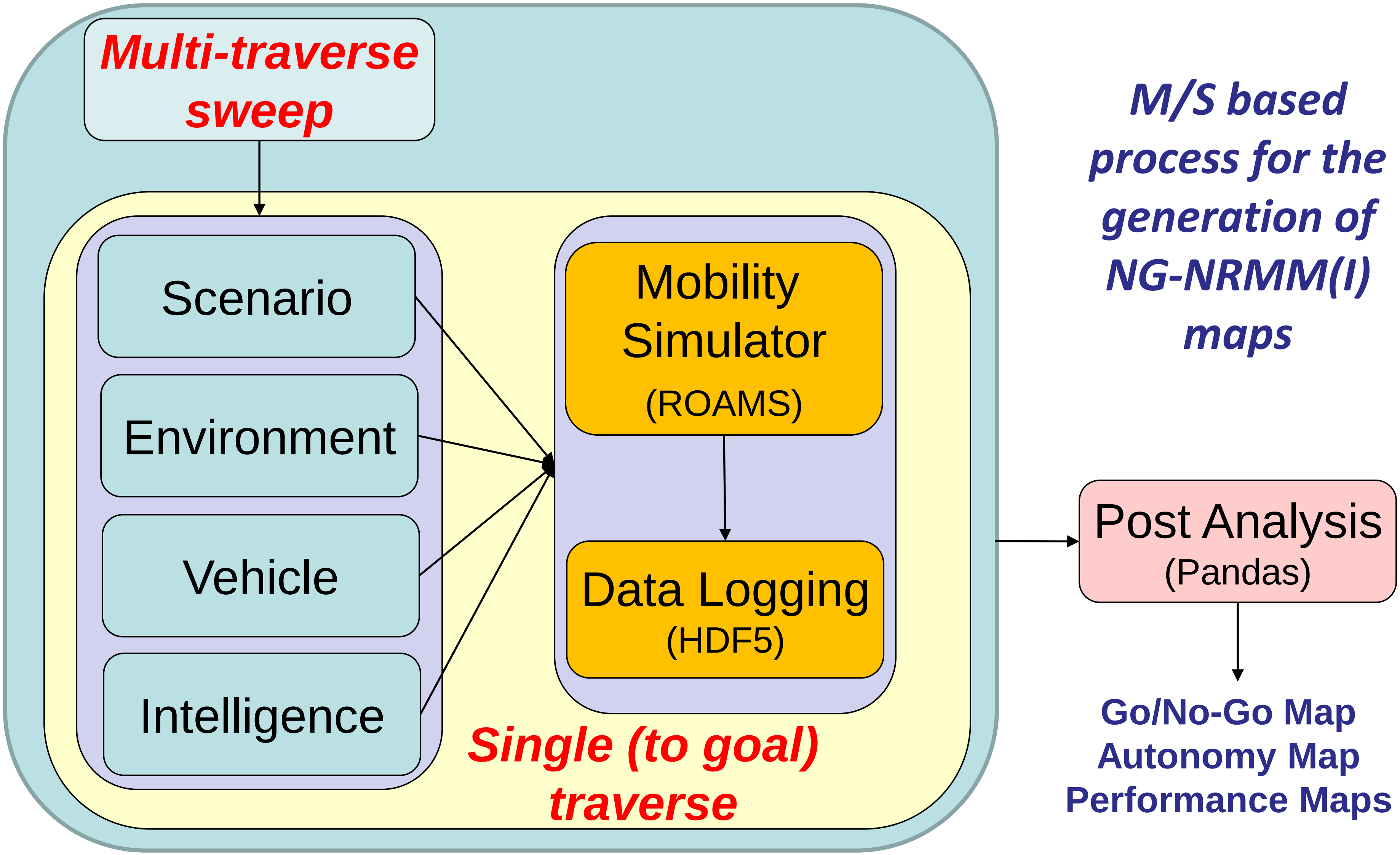
Rocker-Bogey, skid-steered, legged, double wishbone & trailing armsuspension vehicles; off road & urban scenarios

Topography with discrete hazards

Monterey terrain data set from Team 1



Simulation Setup



Multiple Prototype Experiments

NG-NRMM(I) Experiments

Multiple slope hazard thresholds (10 & 22 degrees)

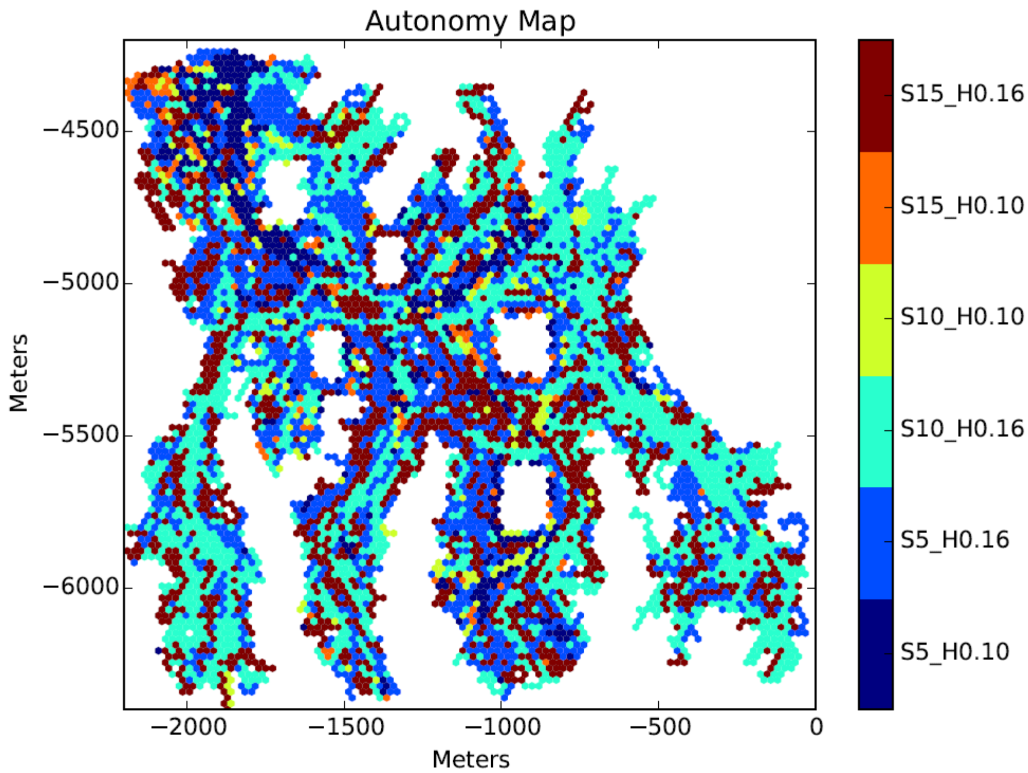
Multiple levels of discrete hazards (dense/moderate/sparse)

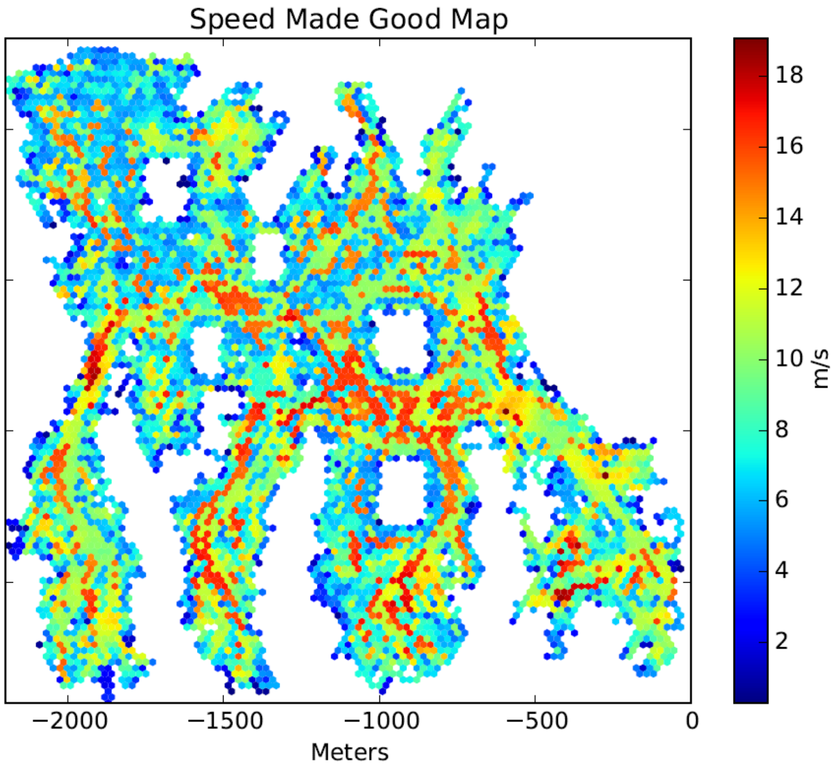
Flat and GIS variable topography

Blind and obstacle avoidance autonomy

Multiple performance metrics (safety vs safety+speed)

Autonomy & Speed made good maps with the global path planner





There is a clear preference for the higher 15deg hazardous slope threshold value, indicating that the vehicle autonomy is capable of handling more aggressive terrain than the conservative 9deg slope threshold.

NG-NRMM(I) Gaps & Challenges

- **Over-arching challenges**
  - Autonomy is malleable – can predictive models keep up with continuing s/w updates
  - Autonomy technology is evolving rapidly
  - Capturing uncertainty; predicting confidence levels
- **Autonomy scenarios**
  - Convoy ops, dismounted soldier & auton. vehicle, moving obstacles, other vehicles etc.
  - Urban scenarios; indoor environments
- **Autonomous mobility modes**
  - Wheeled, tracked, legged, hopping
  - Beyond ground mobility - drones, rotorcraft
- **Operations predictive models**
  - Autonomy map data products and beyond
  - Predictive software models
- **M&S fidelity**
  - Scale up to more complex **realistic** scenarios and environments
  - More **complex autonomy** modules in the loop
  - More **detailed sensor** models
  - Working with **real environment** and GIS data
  - Expanding range of **performance metrics**
- **Process challenges**
  - Scaling up to sample across **larger autonomy parameter space**
  - Using **reduced order** surrogate models and levels of **abstraction**